DEFENCE R&D DÉFENSE

Contaminated Vehicle Protection Factors for the CF Grizzly

D.S. Haslip

Defence R&D Canada

TECHNICAL MEMORANDUM
DREO TR 2001-070
November 2001

National Defence / Défense nationale

Canada

Contaminated Vehicle Protection Factors for the CF Grizzly

D. S. Haslip
Space Systems & Technology Section, Defence Research Establishment Ottawa

Defence Research Establishment Ottawa

Technical Memorandum

DREO TM 2001-070

November 2001

Author

Dean S. Haslip

Approved by

David Liang

Head, Space Systems and Technology Section

Approved for release by

Gordon Marwood

Chief Scientist, Defence Research Establishment Ottawa

Abstract

Measurements of dose rates at 10 locations inside a radiologically contaminated CF Grizzly Light Armoured Vehicle were made at a French army facility. This permits calculation of the radiation protection factors for the locations inside the vehicle. The contaminated vehicle protection factors varied between 3.3 and 6.9, depending on position within the vehicle, averaging 5.7. These values are consistent with previous measurements made at DREO. These results were also used to test DREO's ability to use data from its Source-in-a-Tube simulator to predict dose rates inside a non-uniformly contaminated vehicle. These measurements not only provide a thorough characterization of the radiation protection offered by the Grizzly, but also validate the use of the SIT simulator as a tool for evaluating radiation protection of vehicles.

Résumé

Nous avons fait des mesures des débits de dose à 10 emplacements à l'intérieur d'un léger véhicule blindé (le Grizzly des FC) qui possédait de la contamination radiologique. Ceci permet le calcul des facteurs de radioprotection pour les différents emplacements à l'intérieur du véhicule. Les facteurs de radioprotection du véhicule contaminé sont entre 3,3 et 6,9, dépendant de la position dans le véhicule; en moyenne, le facteur de radioprotection est 5,7. Ces valeurs conforment aux mesures précédentes faites à CRDO. Nous avons également utilisé ces résultats pour évaluer l'efficacité de l'usage des données provenant du simulateur « Source-in-a-Tube » à CRDO pour prévoir des débits de dose à l'intérieur d'un véhicule qui est contaminé de façon irrégulière. Ces mesures fournissent une caractérisation complète de la radioprotection offerte par le Grizzly, et aussi valident l'utilisation du simulateur « Source-in-a-Tube » comme outil pour évaluer la radioprotection des véhicules.

This page intentionally left blank.

Executive summary

Introduction: Radioactive contamination presents many challenges to military operations, not the least of which is that of minimising dose to personnel. For this reason, it is important to understand what degree of radiation protection an armoured vehicle provides to a soldier, both in the situation where the vehicle is clean and when it is contaminated. In this work, measurements of interior dose rates and external contamination levels were combined to determine the radiation protection of the CF Grizzly.

Results: Contaminated vehicle protection factors were evaluated at 10 different locations inside the vehicle; they ranged between 3.3 and 6.9, averaging 5.7. These values are in agreement with earlier work with DREO's Source-in-a-Tube simulator. The results mean that a soldier in a contaminated field can halve his or her dose by getting into a Grizzly, even if that vehicle is also contaminated. This work has also been used to demonstrate that dose rates inside non-uniformly contaminated vehicles can be accurately estimated with results from DREO's Source-in-a-Tube simulator. These estimates, however, are not a lot more accurate than using a single radiation protection factor and an average level of contamination.

Significance: This work has provided a very complete picture of the radiation protection offered by the CF Grizzly. It has also shown the value of DREO's simulator, in that very accurate radiation protection measurements can be obtained without the need for contaminating vehicles. This supports the case for making the simulator a secondary standard in the next revision of NATO Allied Engineering Publication 14.

Haslip D. S., Cousins T., and Jones T. A. 2001. Contaminated Vehicle Protection Factors for the CF Grizzly. DREO TM 2001-070 Defence Research Establishment Ottawa.

Sommaire

Introduction: La contamination radioactive présente plusieurs défis aux opérations militaires, surtout en ce qui concerne la réduction de dose au personnel. Pour cette raison, il est important de savoir quel degré de radioprotection est offert par un véhicule blindé qui est soit contaminé, ou possède aucune trace de contamination. Dans ce travail, nous avons utilisé des mesures des débits de dose à l'intérieur et des niveaux de contamination à l'extérieur pour déterminer la radioprotection du Grizzly des FC.

Résultats: Des facteurs de protection pour le véhicule contaminé ont été évalués à 10 emplacements différents à l'intérieur du véhicule; l'écart de valeurs fut entre 3,3 et 6,9, avec une moyenne de 5,7. Ces valeurs conforment aux premiers essais avec le simulateur « Source-in-a-Tube » du CRDO. Les résultats signifient qu'un soldat dans un champ contaminé peut couper sa dose de moitié en entrant dans un Grizzly, même si ce véhicule est également contaminé. Nous avons aussi employé ces données pour démontrer que nous pouvons estimer des débits de dose dans des véhicules qui sont contaminés de façon irrégulière avec des résultats du simulateur « Source-in-a-Tube » du CRDO. Ces évaluations, cependant, ne représentent pas des données qui sont terriblement plus précises que les données que produirait un calcul utilisant un facteur simple de radioprotection et un niveau moyen de contamination.

Importance: Ce travail a fourni une image très complète de la radioprotection offerte par le Grizzly des FC. Il a également montré l'efficacité du simulateur « Source-in-a-Tube » du CRDO, en faisant des mesures très précises de radioprotection, sans besoin de contaminer des véhicules. Ceci supporte l'argument pour déclarer notre simulateur comme une norme secondaire dans la prochaine révision de AEP-14 de l'OTAN.

Haslip D. S., Cousins T., et Jones T. A. 2000. Facteurs de radioprotection pour un véhicule contaminé (le Grizzly des FC). DREO TM 2001-070 Centre de recherche pour la défense Ottawa.

Table of contents

This page intentionally left blank.

List of figures

List of tables

1. Introduction

With the end of the cold war, the character of the radiological threat to the Canadian Forces (CF) has changed considerably. Although the prospect of nuclear weapons exchange is greatly reduced, deployed forces in operations from wartime to peacekeeping are now concerned with the prospect of radiological dispersal weapons or the fallout from sabotaged or damaged nuclear reactors. All of these scenarios can produce widespread contamination, which could impact CF operations.

Conducting operations in a contaminated environment carries a number of challenges. Decontamination and transport regulations are some of these, but during the operation the biggest challenge is minimising contamination and exposure of personnel. An obvious approach to achieving this goal is to encourage personnel to remain inside vehicles, as opposed to walking through contaminated zones. This will certainly cut down on contamination and on the risk of internal dose, but the extent to which it reduces external dose is far less certain and is dependent on a number of factors, including the radionuclide involved, the contamination pattern on the ground and on the vehicle, and the locations of personnel within the vehicle. The protection offered to personnel inside a contaminated vehicle is the topic of this paper.

In September 1999, DREO personnel carried out radiological decontamination trials in collaboration with French researchers. A Canadian Forces Armoured Personnel Carrier (the Grizzly) was contaminated with radioactive Lanthanum-140, and then decontaminated. The results of the decontamination trials have been reported in a previous document [1], however these trials also offer the opportunity to measure the radiation protection offered by this vehicle to personnel inside. This document summarises these results.

2. Experiment

The trials were performed at the Centre Décontamination et Études de Protection (DEP) at the Établissement Technique de BourgeS (ETBS) in September of 1999. The contaminant was sand loaded with radioactive ^{140}La. The sand particles have a mean diameter between 100 and 200 microns, typical of nuclear weapons fallout. ^{140}La is a beta-gamma emitter with a complicated energy spectrum for both betas and gammas; it is a reasonable simulant for the fission products typical of fresh nuclear fallout.

The contamination of the vehicle was described in detail in reference [1]. In summary, the vehicle is pre-wetted to improve adhesion, and the contamination takes place in a closed facility to minimise the spread of airborne radioactivity. The radioactive sand falls from an automated system on the ceiling of the contamination chamber, producing a contamination pattern in the room that is constant to within about 23%. Once the contamination has settled onto the ground and the vehicle, the vehicle is towed outside and into the ETBS contamination measurement apparatus, pictured in Figure 1. The ETBS "cage" supports 77 Geiger tubes that are placed such that, when the cage is closed around the vehicle, each tube sits in a reproducible location within a few centimetres of the vehicle surface. Each tube's dose rate, therefore, is a reasonable measure of the local contamination of the vehicle surface. Only the first set

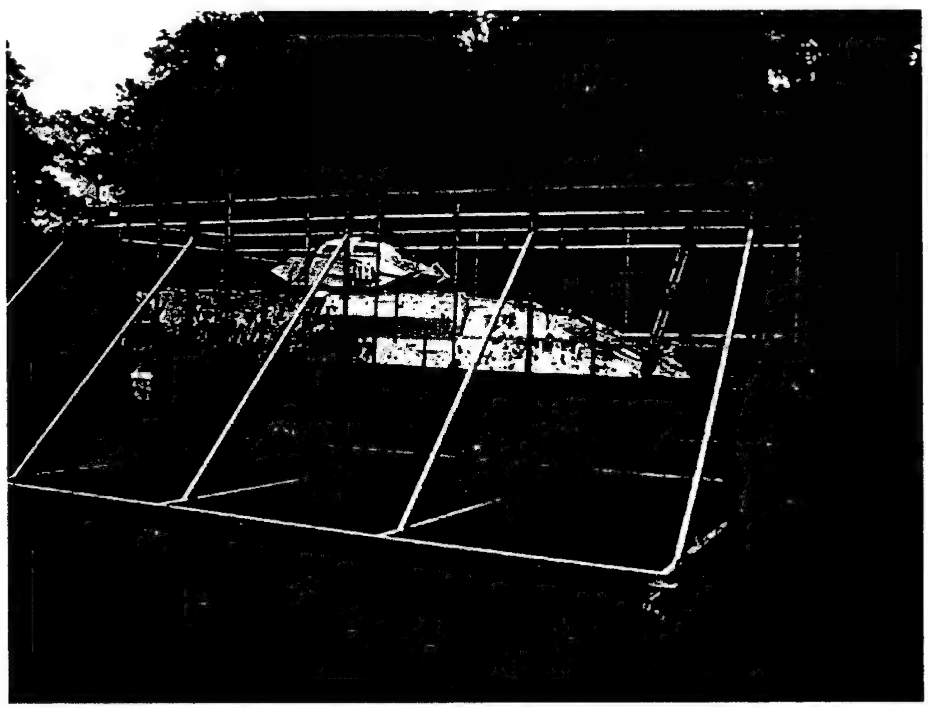

Figure 1. *The ETBS cage for measuring vehicular contamination. Seventy-seven Geiger tubes are suspended from the metal structure; when the cage is closed around the vehicle, these tubes are within a few centimetres of the vehicle surface.*

of tube measurements, taken immediately after contamination and before any decontamination, is used in this report.

To monitor interior dose rates, ten electronic dosimeters (Siemens EPD-2s) were placed at various locations inside the vehicle for the duration of the experiment. The dosimeters were programmed to save their integrated dose to memory every two minutes, for later retrieval by a PC. These doses allow the construction of a dose rate profile for the entire experiment, with a two-minute timescale. For this work, only the dose rates measured at the time of the first cage measurement are of interest. For all dosimeters, the dose rates are constant (within uncertainties) over this period of time.

3. Protection Factor Measurements

The dose rates measured by the electronic dosimeters inside the Grizzly can be used to calculate the radiation protection offered by the vehicle. This section of the paper deals with this facet of the results.

A common concept in radiation protection is that of a "shielding factor", the ratio of dose rate measured by a device in an unshielded situation to that measured in a shielded configuration. As applied to vehicles, one such quantity is the vehicle protection factor (VPF) [2], defined as the ratio of the free-field dose rate at one metre (NATO reference height) above an infinite uniformly contaminated field (DR_{ff}) to the dose rate at a given position inside a vehicle parked in the same field (DR_v). That is,

$$VPF = \frac{DR_{ff}}{DR_v}.$$

The VPF is obviously a function of the position of the measurement point inside the vehicle. This quantity is very useful, but it does not tell the whole story. Namely, while it recognises the protection offered by the vehicle from radionuclides on the ground, it ignores the fact that the vehicle will almost surely be contaminated itself, either as a result of being in the area when the fallout settled, or from driving through the contaminated field. This contamination can be just as significant to the occupant as the ground contamination in terms of the dose rate it delivers, since it is often so much closer to the occupant.

In a previous work [3], a second protection factor was used that applies specifically to contaminated vehicles. This contaminated vehicle protection factor (CVPF) is defined as the ratio of the free-field dose rate at one metre above an infinite uniformly contaminated field (DR_{ff}) to the dose rate at a given position inside a vehicle uniformly contaminated to the same level as the field (DR_{cv}). Note that in the second instance the field is not contaminated. Thus,

$$CVPF = \frac{DR_{ff}}{DR_{cv}}.$$

The CVPF is an unusual quantity since it compares dose rates for two situations in which the environments themselves are different. However, it is useful because the VPF and the CVPF together can be used to construct what might be called the "ultimate vehicle protection factor" (UVPF), the ratio of free-field dose rate to dose rate inside a contaminated vehicle in a contaminated field. UVPF would be expressed as

$$UVPF = \frac{DR_{ff}}{DR_v + DR_{cv}} = \frac{1}{\frac{1}{VPF} + \frac{1}{CVPF}}.$$

In order to calculate the CVPF for a given position in a vehicle, one must know two things, the contamination level and the dose rate inside. These measurements are discussed below.

The dose rates measured by the Geiger tube cage are shown in Figure 2. The rates vary by well over one order of magnitude, from 7 μGy/h to 421 μGy/h. Previous experiments [4] suggest that the relation between dose rate and contamination is approximately 1.65 (μGy/h)/(MBq/m^2) for ^{140}La. Thus, contamination levels vary between 4.2 and 255 MBq/m^2. This presents a problem, since protection factors are defined for uniform contamination patterns. As a result, protection factors may be skewed because of irregularities in contamination, and furthermore the choice of a contamination level for the calculation is not necessarily obvious.

Various average contamination levels are found in Table 1, corresponding to different sets of vehicle surfaces. The most obvious choice is to average all measurements,

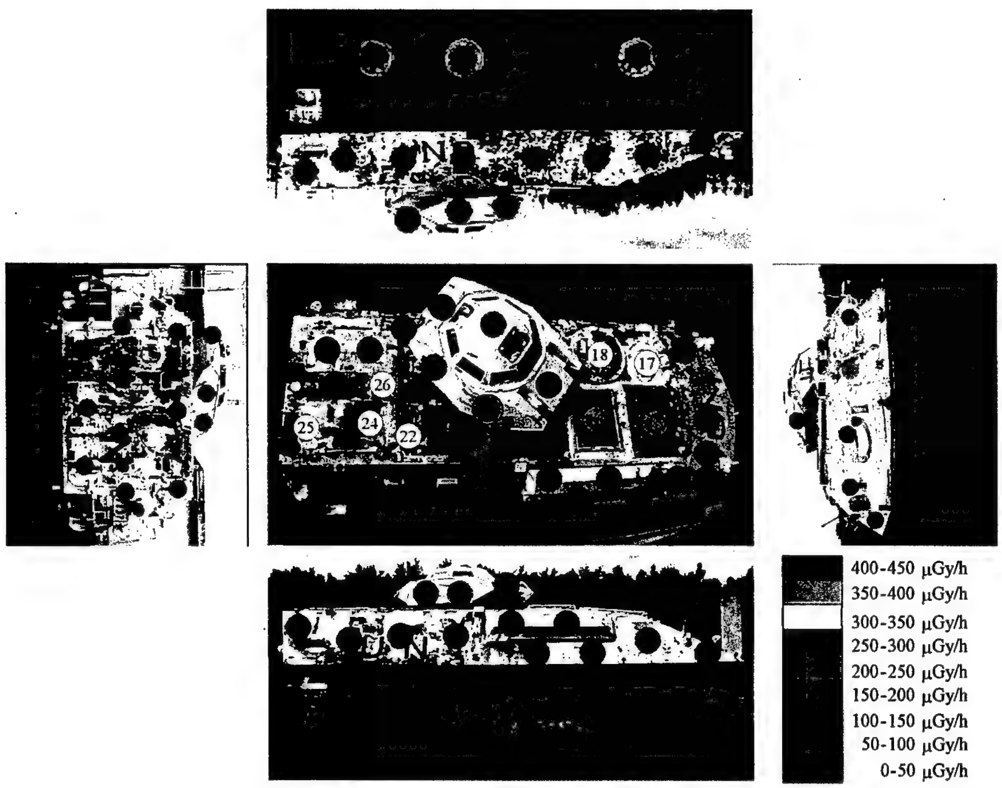

Figure 2. *Dose rates measured by the ETBS Geiger tube cage. The conversion factor from μGy/h to MBq/m^2 is approximately 0.6.*

Table 1. *Average contamination levels for different sets of surfaces on the Grizzly. Also shown is the 1-metre free-field dose rate for an infinite field contaminated at that level with ^{140}La.*

	Surfaces Averaged			
	All Surfaces	**Not Under Nose or at Rear**	**No Downward Facing Surfaces**	**Only Surfaces on Top**
Contamination (MBq/m^2)	80	98	133	185
1-m Dose Rate (mSv/h)	0.70	0.86	1.17	1.63

which gives a contamination of 80 MBq/m^2. The next logical choice is to exclude "downward-facing" surfaces (see reference [1]). These include the underside of the nose, the rear of the vehicle, and the lower half of the vehicle sides (at and just above the wheels). These areas were minimally contaminated at ETBS, and tend to contribute somewhat less to interior dose rates than other surfaces because of their distances from most points of interest within the vehicle. Another possible set of vehicle surfaces is the top surfaces of the vehicle (top of the nose, along the roof, and the top of the turret). This would probably not be a representative average for most points inside the vehicle (except possibly in the turret), but it gives an upper limit to the applicable contamination levels. A fourth set is listed in the table, that being all surfaces except the rear of the vehicle and the underside of the vehicle. This is listed for commonality with previous DREO work [3] (see below).

Dosimeters were placed at 10 locations inside the Grizzly. These locations are listed in Table 2. There are two dosimeters in the driver position, one at head height for someone seated in the turret, one behind the engine block at waist height, and six on the passenger benches located along the centreline of the vehicle, towards the rear. Some are located at the forward end of the bench, and some are located much closer to the rear door. Some are located on the left (driver's)-side bench, and some on the right. Most are located on the seat itself, but some are at chest or head height for a seated soldier. With this in mind, the location descriptions in the table should be clear.

Table 2 also lists the dose rates measured at each of these ten positions at the same time as the cage measurement of external contamination. These dose rates have been corrected for the known 12% under-response of these dosimeters to ^{140}La gamma rays [5]. With these dose rates, it is possible to calculate a CVPF. The table includes four evaluations of the CVPF, corresponding to each of the four contamination levels given in Table 1.

Before examining these numbers in detail, it is useful to ask whether they are accurate. In an earlier paper, CVPF's were measured for the CF Grizzly with DREO's "Source

Table 2. Dose rates measured at 10 locations inside the Grizzly at DEP. Contaminated Vehicle Protection Factors are given for the four contamination levels proposed in ***Table 1****.*

Position Inside Grizzly	Dose Rate (μSv/h)	CVPF for Various Contamination Averages			
		All Surfaces	No Under Nose / No Rear	No Down Surfaces	Only Top Surfaces
Driver's Head	262.5 ± 4.8	2.68	3.28	4.45	6.19
Driver's Seat	128.9 ± 5.0	5.46	6.68	9.07	12.62
Turret - Head	201.1 ± 4.8	3.50	4.28	5.81	8.08
Engine - Waist	149.3 ± 5.0	4.71	5.77	7.83	10.89
Left Front Bench - Seat	130.2 ± 2.2	5.40	6.61	8.98	12.49
Right Front Bench - Seat	137.0 ± 2.2	5.13	6.29	8.53	11.86
Left Front Bench - Chest	143.2 ± 4.5	4.91	6.02	8.16	11.36
Left Rear Bench – Seat	125.5 ± 4.8	5.60	6.87	9.32	12.96
Right Rear Bench – Seat	127.5 ± 3.3	5.51	6.76	9.17	12.75
Centre Rear Bench - Head	200.5 ± 4.8	3.51	4.30	5.83	8.11

in a Tube" (SIT) simulator[1] [3]. The two positions assessed at that time were the driver's seat and a position at chest height near the front of the left bench. The CVPFs for these two locations were evaluated at 7.79 and 5.30, respectively[2]. When compared to the CVPFs for the "Driver's Seat" and "Left Front Bench – Chest" in Table 2, we see that the earlier values are in best agreement with the second column of values (No under nose / No rear). This is encouraging because the original SIT trials also excluded contamination on these surfaces.

The current values of 6.7 and 6.0 are in reasonable agreement with the earlier values of 7.8 and 5.3, with discrepancies of order 14%. However, the problem is that the discrepancies are in different directions for the two positions, and so the ratio of the two protection factors (giving the relative protection for two locations within the vehicle) is uncertain by almost 30%. Thus, it is important to understand this discrepancy. The most likely origin of the discrepancy is the non-uniformity of the contamination in this work (as compared to the uniformity of the SIT system). Namely, in the present work the contamination level is much higher on the horizontal surfaces, and considerably lower on the sides. Because the driver's seat is in the nose of the vehicle, this position is very close to a highly contaminated area. This results in

[1] Note that the SIT simulator used ^{60}Co, and this work used ^{140}La, and that protection factors are isotope-dependent. However, because the average gamma-ray energies are not so different (1253 keV for ^{60}Co, 962 keV for ^{140}La), and because the CVPF involves ratios of dose rates, the difference is only about 3% (PF higher for ^{140}La)

[2] The reference actually gives these values as 11.9 and 8.0, respectively. The difference is due to a re-evaluation of the free-field dose rate with a newer more reliable computer code. The earlier in-vehicle measurements are still valid.

higher-than-expected dose rates and a smaller protection factor, as observed. Conversely, the left bench position should be affected considerably by contamination on the left side of the vehicle. These are contaminated at lower-than-average levels, resulting in higher protection factors. Thus, it is expected that the non-uniformities in the contamination can be used to explain most of the observed discrepancies. However, one must be careful not to take SIT results as "correct" and attempt to correct values as collected here. The fact remains that the experimental data collected in this work may be more representative of field conditions because the contamination pattern resulted from (simulated) fallout onto a vehicle, and was not ideal.

With the discrepancies understood, one can move on to comparing the ten CVPF values derived from this work. The lowest CVPF by far is for the "Driver's Head", which results from this position's proximity to the large heavily-contaminated hood of the vehicle. A similar situation obtains for the "Turret Head" position, and even for the "Centre Rear Bench – Head" position, which is moderately close to the heavily contaminated roof of the vehicle, and also to the less contaminated rear doors. The other "Bench" positions are approximately equivalent, with relatively large CVPFs. These positions are far from any given contaminated surface, and as such benefit from the decrease in dose rate with distance from a radioactive source. One of the most protected locations is the "Driver's Seat", despite its proximity to the contaminated hood. Although the seat is relatively close to the underside of the nose, this part of the vehicle was only very lightly contaminated. More important, the driver is in one corner of the vehicle, and so is quite far from most of the contamination on the vehicle. Thus, the protection factor gradients (such as from the driver's seat to the driver's head) can be appreciable in this section of the vehicle. The position behind the engine block has a protection factor that is neither particularly high nor low. Depending on the location of the dose measurement point, the engine block can often be relied on to give significant radiation protection. However, the engine block in this vehicle was largely removed, so this effect was absent. In addition, with this dose point being closer to the side of the vehicle than the bench positions, one might expect smaller protection factors, as observed.

The average protection factor for the ten locations measured is 5.7. As discussed in the previous section, this number is not useful, since it compares two completely different scenarios. However, combined with a conventional VPF, it can be used to produce an "ultimate vehicle protection factor". Although a conventional VPF has not been assessed for the Grizzly, we may assume a value of 3.0, in accordance with earlier results on the CF Bison [6]. This gives a UVPF of 2.0, indicating that a soldier standing in a contaminated field can cut his dose rate in half by getting inside a vehicle, even when the vehicle itself is contaminated.

4. Predictive Power of DREO's SIT System

4.1 Background

Several mentions have appeared in this paper of DREO's SIT system. With this system, a milliCurie-range ^{60}Co source is pulled through a tube draped over a vehicle (as in Figure 3). By positioning the tube at numerous positions along the length of the vehicle, a complete picture of the vehicle's radiation shielding can be produced. Furthermore, if one uses a time-sensitive detector in the vehicle, one can assess the dose rate at the measurement point due to contamination at any given point on the vehicle. In previous work [3], the SIT system has been used only to calculate protection factors, which assume uniform contamination. However, because the SIT system provides radiation-shielding information as a function of contamination position, it could also be used to calculate radiation dose rate at a point inside a non-uniformly contaminated vehicle. Such a calculation is the focus of this section.

In the trials of the SIT system, experimental data were collected for 19 different tube positions, starting at the tip of the nose of the vehicle, and at intervals of 30 cm toward the rear of the vehicle (marked by white tape in Figure 3). Two radiation detectors were placed inside the vehicle. DREO's Airborne Spectroscopy System [7] was placed on the driver's seat; it collected dosimetric data every second, and therefore produced a complete picture of the radiation protection offered by the vehicle. A BGO detector was placed on the passenger bench at chest height, and collected dosimetric

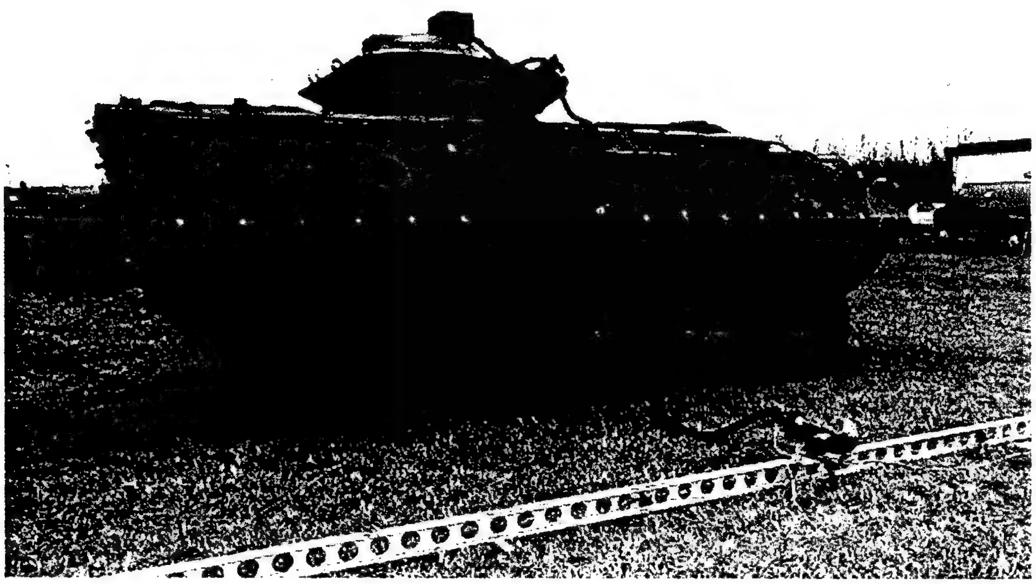

Figure 3. *DREO's SIT system. A ^{60}Co source is pulled over the Grizzly through the black tube shown. By varying the tube position, a detailed picture of the protection offered by the vehicle can be produced.*

data for each tube position, and thus produced a somewhat less complete picture of the vehicle's radiation protection.

4.2 Theory

Consider first the data that are obtained by a sensor such as the DREO Airborne System in an SIT trial. These data show the dose rate per unit contamination at the sensor location as a function of the location of the contamination. These data could be indexed as *D(x,y)*, where *x* indicates the position of the tube, and *y* indicates the position of the source along the tube (and thus the left-to-right position of the source over the vehicle). In fact, this approach is even more manageable if *y* specifically denotes locations on the vehicle (eg: top, lower left, etc.), and not individual data points. If one could measure the contamination in some real-life situation at the same locations *C(x,y)*, then the dose rate at the sensor position could be evaluated via the expression

$$DR = \sum_{i,j} D(i,j)C(i,j)$$

where the summation is over all tube positions *i* and source positions *j*. If we treat *D* and *C* as *m*-by-*n* matrices (*m* tube positions, *n* position designators), then this expression becomes

$$\begin{aligned} DR &= \sum_{i=1}^{m}\sum_{j=1}^{n} D(i,j)C(i,j) \\ &= \sum_{i=1}^{m}\sum_{j=1}^{n} D(i,j)C^{-1}(j,i) \\ &= \sum_{i=1}^{m} DC^{-1}(i,i) \\ &= \text{trace}(DC^{-1}) \end{aligned}$$

where C^{-1} is the inverse of the matrix *C*, and trace(DC^{-1}) indicates the sum of the diagonal elements of the matrix product DC^{-1}. Incidentally, $DC^{-1}(i,i)$ is the dose rate at the sensor position due to contamination at the i^{th} tube position; the off-diagonal elements of the matrix product are non-physical, denoting the dose rate from contamination at position *i*, if the contamination at that position was equal to that measured at position *j*.

A similar but simpler expression obtains in the case of a sensor like DREO's BGO detector, where the data is restricted to dose rates per unit contamination for each tube position *D*(*i*). If we denote the measured contamination at each tube position in some real-life situation as *C*(*i*), then the expected dose rate at the sensor position is equal to

$$DR = \sum_{i=1}^{m} D(i)C(i)$$

which is actually equivalent to the "trace" expression given above, if one considers the data $D(i)$ and the contamination measurements $C(i)$ to each be m-by-1 matrices.

4.3 Results

Measurements from the SIT trials are summarised in Table 3. For the purposes of this work, the Grizzly surface is subdivided into 95 regions. Along the length, the subdivision corresponds to the 19 tube positions. Each tube position is then divided into 5 sub-regions: the largely horizontal top surface, and the left- and right-side surfaces above and below the "crease" in the bodywork (above the wheel wells, where

Table 3. Measurements made during SIT trials.

	Airborne System (µSv/h)					BGO System (µGy/h)
Tube Position (feet from front)	**Lower Left**	**Upper Left**	**Top**	**Upper Right**	**Lower Right**	
0	1.89	2.51	10.72	0.19	0.17	0.71
1	2.01	4.20	12.51	0.21	0.22	0.62
2	4.35	8.51	17.83	0.11	0.08	1.15
3	5.41	8.25	28.20	0.21	0.15	1.55
4	5.04	6.19	40.07	0.61	0.17	1.60
5	11.42	5.62	46.86	0.67	0.24	2.32
6	16.27	22.73	41.85	1.13	0.75	2.44
7	11.73	12.34	28.61	2.42	0.68	3.36
8	7.04	9.10	15.41	1.86	0.48	5.59
9	4.58	5.02	7.55	0.89	0.47	12.69
10	1.92	3.26	4.48	0.49	0.39	17.57
11	1.21	2.11	2.29	0.72	0.27	20.07
12	0.90	1.71	1.49	0.55	0.17	29.38
13	0.52	0.83	2.08	0.55	0.16	46.26
14	0.37	0.94	2.24	0.38	0.17	70.31
15	0.20	0.41	1.55	0.29	0.19	117.14
16	0.11	0.24	1.07	0.28	0.18	103.04
17	0.09	0.16	1.27	0.22	0.12	64.60
18	0.08	0.17	0.91	0.21	0.06	42.91

Table 4. Results of the SIT predictive calculation.

	Dose Point	
	Driver's Seat	Chest Height – Passenger Bench
Predicted Dose Rate (μSv/h)	170	156
Lanthanum-corrected Rate (μSv/h)	150	137
Measured Dose Rate (μSv/h)	129	143

the white tape is visible in Figure 3). Most of Table 3 shows the airborne dose rates, normalized to show the expected dose rate at the driver's seat corresponding to a uniform contamination of 1 $\mu Ci/cm^2$ in each of the 95 surface regions. The table also shows the BGO detector dose rates, normalized to show the expected dose rate at chest height on the passenger's bench corresponding to a uniform contamination of 1 $\mu Ci/cm^2$ in each of the 19 surface regions defined by the tube positions. These are, therefore, the 20-by-5 and 20-by-1 "*D*" matrices described in the previous section. The contamination matrices "*C*" are not tabulated in this document, although the content of the matrices is summarised in Figure 2.

The results of the "matrix multiplication" are shown in Table 4. The first row of figures contains the raw predictions of the calculation, based on measured dose rates in the SIT trials and measured contamination levels in the decontamination experiment. It should be noted that these calculations assume that the contaminant is ^{60}Co, which was used in the SIT trials. This isotope has a somewhat harder (higher average energy) gamma-ray spectrum than ^{140}La, resulting in higher calculated dose rates than should actually have been observed. Microshield calculations suggest that for a typical vehicle, the dose rate from ^{140}La should be about 88% of the value from ^{60}Co. These values are given in the second row of the table. The final row of the table gives the dose rates measured by the electronic dosimeters at the same positions inside the vehicle during the decontamination experiment.

The predicted rates in Table 4 are in good agreement with the measured rates, differing by only +16% and –5% for the driver's seat and passenger bench positions, respectively. One might expect better agreement for the driver's seat position, and it is not clear from where the discrepancy arises. It is possible that the calculation overestimated the dose from contamination on the sides of the vehicle. The SIT system assumes that the vehicle extends all the way to the ground, ignoring the clearance beneath the vehicle. However, this probably does not amount to more than about 4 μSv/h, and there are no other obvious deficiencies in the scheme. Nevertheless, it is heartening to see that one can reproduce internal dose rates to this degree of precision in this way. It might also be noted, however, that these results are not much more accurate than if one had used a measured protection factor and an average contamination level.

5. Conclusions

This work has first measured the contaminated vehicle protection factor for 10 locations inside the CF Grizzly. These vary between 3.3 and 6.9, depending on the location. The mean protection factor for the 10 locations is 5.7. These values are somewhat uncertain because the vehicle contamination was not uniform. In that sense, these values might be seen to be more representative of field conditions, assuming that the contamination fell from above. Values for two of the locations can be compared to previous work with DREO's SIT system. These values are consistent within 15%, with most of the discrepancy likely due to the non-uniformity of the contamination. When combined with a conventional vehicle protection factor of 3.0, this yields an "ultimate vehicle protection factor" of 2.0, indicating that an individual in a contaminated vehicle in the middle of a contaminated field receives half of the dose that they would receive if they were standing in that same field.

This work has also tested the predictive power of DREO's SIT system, in that we have used experimental results from this system to predict the dose rate at two locations inside the Grizzly given only the contamination levels outside. This is considerably more sophisticated than attempting to reconstruct dose rates from protection factors, which must assume some pattern of contamination. The predictions presented in this work were accurate to within 15%, a considerable achievement. Nevertheless, it is worthwhile to note that these predictions are not a lot more accurate than those based on a protection factor alone, although one has somewhat more confidence in the more sophisticated approach.

6. References

1. Haslip D.S., Cousins T., and Hoffarth B.E. (2001). Efficacy of Radiological Decontamination (DREO TM 2001-060). Defence Research Establishment Ottawa.

2. NATO (1993). Guidelines for the Armoured Vehicle Designer to Improve Nuclear Radiation Protection , Edition 3 (NATO AEP-14). NATO. (NATO Restricted)

3. Haslip D.S., Cousins T., Brisson J.R., Hoffarth B.E., Jones T.A., and Dubeau J. (March 1999). Measurement of Radiation Protection Factors for Contaminated Vehicles (DREO TM 1999-070). Defence Research Establishment Ottawa.

4. Heimbach C.R. and Oliver M.A. (1998). Research Project of the Radiation Fallout Tests at Etablissement Technique de Bourges (ETBS) (ATC-8124). U.S. Army Aberdeen Test Center.

5. Haslip D.S., Cousins T., Waller E.J., Kehlet R.A., Heimbach C.R., Oliver M.A., Kaul D.C., Boltwood M.F., Toqué C., and Eleftherakis A. (2000). Low-Level Radiation Dosimetry Intercomparison (TTCP TR-CBD-AG44-1-2000, DREO SL 2000-067). Defence Research Establishment Ottawa.

6. Cousins T., Jones T.A., Hoffarth B.E., and Brisson J.R. (October 1996). Evaluation of the Gamma-Ray Protection Factor of the New CF LAV, Final Tasking Report to PMO LAV: Project L265, FE #847696FGFA5. Defence Research Establishment Ottawa.

7. Bubble Technology Industries Inc. (November 1997). Development of Airborne Miniature Radiation Spectroscopy System with GPS (Contract #W7714-6-0048/001/SV). Bubble Technology Industries Inc.

Distribution list

External (DRDCIM 3 Distribution Responsibility)

General
1 - ADM(S&T) (for distribution)
1 - DSTHP
1 - DRDCIM 3
1 - J2 STI
1 - RMC (Dr. L.G.I. Bennett)
1 - DRES
1 - Canadian Forces College Library
1 - CFANS Library
2 - DNBCD (LCdr R. A. Wall, Mr. M. Williams)

Land
1 - DSSPM (CWO A. MacDonald)
1 - Fort Frontenac Library
1 - DLR (Maj E. Urbanowicz)

Maritime
1 - DMPPD (LCdr A. Cerins)

Air
1 - A3 RDNS (Maj. A. Hoey)

Communications and Space
1 - DTSES

Other Government Departments
1 - CISTI
2 - National Library of Canada

Foreign
1 - NDHQ/British Army Standardization Representative (BASR)
1 - NDHQ/US Army Research, Development & Standardization Group - Canada (USARDG-C)
1 - United Kingdom, MOD/DRIC
1 - New Zealand, Librarian MOD
1 - USA / DTIC
1 - NATO C3 Agency
1 - Netherlands / TDCK
1 - Australia / DISNO Defence Centre Canberra
1 - France, CEB (Dr. J. Dhermain)
1 - France, CEB (Dr. Ph. Bouteilloux)
1 - Australia, AMRL (Dr. Errol O'Donovan)
1 - USA, DTRA (Mr. Robert Kehlet)

Internal: DREO (DREO Distribution Responsibility)

1 - Dean S. Haslip
1 - Tom Cousins
1 - Trevor A. Jones
4 - DREO Library

Distribution Summary

DRDCIM Distribution	DREO Distribution	Total
32	7	39

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)

Defence Research Establishment Ottawa
Ottawa, Ontario
K1A 0Z4

2. SECURITY CLASSIFICATION (overall security classification of the document, including special warning terms if applicable)

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)

Contaminated Vehicle Protection Factors for the CF Grizzly (U)

4. AUTHORS (Last name, first name, middle initial)

Haslip, Dean S.

5. DATE OF PUBLICATION (month and year of publication of document)

November 2001

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)

13

6b. NO. OF REFS (total cited in document)

6

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

DREO Technical Memorandum 2001-070

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.)

Space Systems & Technology Section
Defence Research Establishment Ottawa
Ottawa, Ontario K1A 0Z4

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

6qe11

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DREO Technical Memorandum # 2001-070

10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

Unlimited Announcement

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

Measurements of dose rates at 10 locations inside a radiologically contaminated CF Grizzly Light Armoured Vehicle were made at a French army facility. This permits calculation of the radiation protection factors for the locations inside the vehicle. The contaminated vehicle protection factors varied between 3.3 and 6.9, depending on position within the vehicle, averaging 5.7. These values are consistent with previous measurements made at DREO. These results were also used to test DREO's ability to use data from its Source-in-a-Tube simulator to predict dose rates inside a non-uniformly contaminated vehicle. These measurements not only provide a thorough characterization of the radiation protection offered by the Grizzly, but also validate the use of the SIT simulator as a tool for evaluating radiation protection of vehicles.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Radiation Detection, Contamination, Protection Factor, Simulation

Defence R&D Canada

is the national authority for providing
Science and Technology (S&T) leadership
in the advancement and maintenance
of Canada's defence capabilities.

R et D pour la défense Canada

est responsable, au niveau national, pour
les sciences et la technologie (S et T)
au service de l'avancement et du maintien des
capacités de défense du Canada.

DEFENCE R&D DÉFENSE

www.drdc-rddc.dnd.ca